Exam Water Quality

Master Civil Engineering and Management

Course code:	201800023
Date:	October 26, 2020
Location:	OH 111
Time:	13:45-16:45 *(17:30 for students with right of extra time (25%))*
Lecturer:	D.C.M. Augustijn

Type exam: Closed book

Appendix: Information sheet Water Quality

Instructions:

- This exam consists of three parts: 10 true/false questions, 5 multiple choice questions (with four options of which only one is correct) and 4 open questions. The true/false questions each value 1 point, multiple choice questions each value 2 points, and the open questions value at total of 25 points (the number of points are indicated per subquestion). A partly correct answer to an open question is awarded part of the allocated points.
- Write the answers on the provided answer sheets. Write your name on each separate sheet. The blank pages in the middle can be used as scrap paper.
- You have 3 hours for the entire exam. Plan your exam well.
- This is a closed book exam, so you are not allowed to use any books or notes, except the information sheet which is handed out at the beginning of the exam.
- You may use dictionaries (no digital versions).
- You may use a (graphical) calculator.
- Answer the questions in English (language errors are not lowering your grade).
- In answering the questions, be concise and clear.
- Hand in the answer sheets and information sheet, these questions and the scrap paper you can take home.

Good Luck!

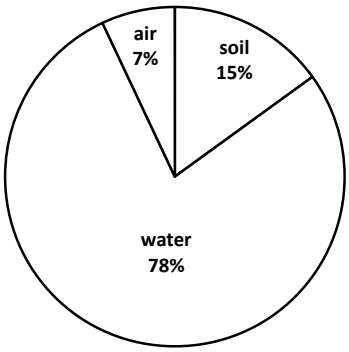
Section 1: True/False *(10 points)*

Indicate for each of the following statements whether the statement is **True** or **False**:

1. Groundwater is not part of the EU Water Framework Directive. **False**
2. Tributyltin is typically used as an anti-fouling paint on ships. **True**
3. In the Netherlands municipalities are responsible for the sewer system and water boards for the waste water treatment. **True**
4. A dipole is an element that emits both alpha and gamma radiation. **False**
5. Biogas (CH_4) is produced during fermentation under strong anaerobic conditions. **True**
6. When a lake is contaminated and flushed with clean water, the remediation time is longer when the contaminant is adsorbed, even when equilibrium conditions apply. **True**
7. When the dissolution of a salt is an exothermic reaction the solubility increases with increasing temperature. **False**
8. The diffuse double layer refers to a stratified lake. **False**
9. To reduce the effects of eutrophication the load of all nutrients needs to be reduced proportionally. **False** (of one might be sufficient)
10. It is not uncommon that only a small fraction of a particular medicine is taken up by a human body, for example 90% of the intake of paracetamol is excreted. **True**

Section 2: Multiple-choice questions *(10 points)*

Question 11: The figure below gives the equilibrium mass distribution of a certain organic chemical over three different environmental compartments (7% in air, 15% in soil, 78% in water).



Assume that the Henry-coefficient of this component was underestimate, so the Henry- coefficient is in reality higher. Which of the following statements about the change in mass distribution of the chemical over de different compartments is most correct?

A. The mass in air increases, the masses in soil and water decrease.
B. The masses in air and water increase, the mass in soil decreases.
C. The masses in air and soil increase, the mass in water decreases.
D. The masses in water and soil increases, the mass in air decreases.

Question 12: The Secchi depth (SD) is the depth in water at which you still can see a white-black disk (◒) and is an indicator for the clarity or turbidity of the water. Which of the following water quality parameters has no direct relation to the SD?

A. DOC (Dissolved Organic Carbon like humic acids)
B. EC (Electric Conductivity or dissolved salt content)
C. TSS (Total Suspended Solids)
D. Chlorophyll-a concentration

Question 13: When a lake becomes more and more eutrophic it can collapse to a different stable state with different characteristics that remains in place even when the nutrient concentrations are reduced. Which characteristics characterize the state just before the collapse best?

A. High concentration of nutrients, lush vegetation, high turbidity, bottom feeders like bream.
B. Moderate concentrations of nutrients, no vegetation, high turbidity, bottom feeders like bream.
C. High concentration of nutrients, lush vegetation, moderate turbidity, fish that hunt by sight like pike.
D. Moderate concentration of nutrients, no vegetation, moderate turbidity, fish that hunt by sight like pike.

Question 14: An effluent containing organic matter enters a stream. According to the Streeter-Phelps model, the oxygen concentration will drop due to oxygen consumed for the decay of the organic matter and will increase again due to reaeration. When will the oxygen concentration drop the least if all other parameters stay the same?

A. When the stream flow increases
B. When the reaeration rate coefficient k_r decreases
C. When the BOD increases
D. When the degradation rate k_d increases

Question 15: A river is contaminated by a short incidental discharge (Dirac input) of a pollutant from a factory. An authority measures the concentration at two different moments at one location downstream from the point where the pollutant entered the river. The concentration in the first measurement is higher than in the second. Which statement is most likely not true?

A. Both measurements are taken after the peak concentration passed.
B. The first sample is taken before the peak passed, the second sample is taken after the peak passed.
C. The first measurement is taken either before the peak concentration passed, at the peak concentration or after the peak concentration passed.
D. Both measurements are taken before the peak concentration passed.

Section 3: Open questions *(25 points)*

Question 16: Reduction of phosphate concentration in a lake (4 points)
A lake contains too much phosphate causing excess growth of algae. A water manager wants to reduce the phosphate concentration by adding lime ($CaCO_3$) to the lake. The calcium (Ca^{2+}) will react with phosphate (PO_4^{3-}) to the solid calcium phosphate ($Ca_3(PO_4)_2$).

$3Ca^{2+} + 2PO_4^{3-} \rightleftarrows Ca_3(PO_4)_2$

$\Delta G_f^0(Ca_3(PO_4)_2) = -3884.6$ kJ/mole
$\Delta G_f^0(Ca^{2+}) = -553.5$ kJ/mole
$\Delta G_f^0(PO_4^{3-}) = -1018.8$ kJ/mole

a. Calculate the equilibrium constant *K* for this reaction (2).

$\Delta G_t^0 = \Delta G_f^0(Ca_3(PO_4)_2) - 3\Delta G_f^0(Ca^{2+}) - 2\Delta G_f^0(PO_4^{3-}) = -3884.6 + 3*553.5 + 2*1018.8 = -186.5$ kJ/mole

$K = exp\left(-\frac{\Delta G_r^0}{RT}\right) = exp\left(\frac{186500}{8.314 \cdot 298}\right) = 4.9 \cdot 10^{32}$

The current concentration of phosphate in the lake is 100 μg/l. When the lime is added the concentration of calcium (Ca^{2+}) remains constant at 10 μg/l.

b. Calculate to what concentration the phosphate drops as a consequence of the addition of lime. (If you did not find an answer to question 16a, use $K = 5 \cdot 10^{32}$.) (2)

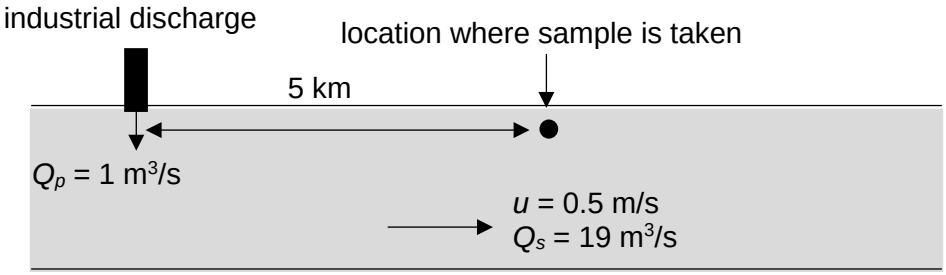
M (Ca^{2+}) = 40.08 g/mole, M(PO_4^{3-}) = 31+4·16 = 95 g/mole
10 μg Ca^{2+}/l = $10 \cdot 10^{-6}/40.08 = 2.5 \cdot 10^{-7}$ mole/l
$K = 4.9 \cdot 10^{32} = \frac{1}{[Ca^{2+}]^3[PO_4^{3-}]^2} \rightarrow [Ca^{2+}]^3[PO_4^{3-}]^2 = 1/(4.9 \cdot 10^{32}) = 2 \cdot 10^{-33}$

$[PO_4^{3-}]^2 = \frac{2 \cdot 10^{-33}}{[Ca^{2+}]^3} \rightarrow [PO_4^{3-}] = \sqrt{\frac{2 \cdot 10^{-33}}{[Ca^{2+}]^3}} = \sqrt{\frac{2 \cdot 10^{-33}}{[2.5 \cdot 10^{-7}]^3}} = \sqrt{\frac{2 \cdot 10^{-33}}{1.56 \cdot 10^{-20}}} = 3.58 \cdot 10^{-7}$ mole/l

$3.58 \cdot 10^{-7} * 95 = 3.4 \cdot 10^{-5}$ g/l = 34 μg/l

[Note: concentrations are fictional and in reality the chemistry is more complex]

Question 17: BOD discharge (7 point)
Organic material is discharged into a stream with waste water from an industrial point source. The discharge of the point sources (Q_p) is 1 m^3/s with a BOD of 20 mg/l. The discharge of the stream (Q_s) is 19 m^3/s and the BOD is negligible. The velocity (u) of the stream is 0.5 m/s. The half-life for first order degradation of the quickly degradable organic matter is 0.5 day. 5 km downstream from the point source a sample is taken to measure the BOD concentration.



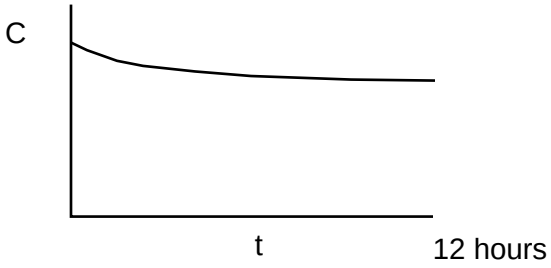
a. Estimate the BOD at the sample location assuming piston displacement. (3)
$Q_3C_3 = Q_1C_1 + Q_2C_2 \rightarrow C_3 = \frac{Q_1C_1+Q_2C_2}{Q_3} = \frac{1\cdot20+19\cdot0}{1+19} = \frac{20}{20}$ = 1 mg/l BOD
5 km = 5000 m → 5000 m/0.5 m/s = 10,000 s = 0.116 d.
k = ln(2)/$t_{1/2}$ = ln(2)/0.5 = 1.39 d^{-1}
$C = C_0 \exp(-kt) = 1 \cdot exp(-1.39 \cdot 0.116)$ = 0.85 mg/l
b. In reality the concentration appears higher. Give two reasons why this could be. (2)
Organic matter not well mixed over cross section yet
Degradation rate is smaller (half-life is longer)
Flow velocity is higher
c. Give two policy measures that can be taken to force the industry to reduce the emission to the environment. (2)
Economical (tax benefits, subsidies, sanctions) and communicative instruments (awareness, positive image, agreements)

Question 18: Kristalbad (10 points)
One of the functions of Kristalbad is the posttreatment of the effluent of the waste water treatment plant in Enschede. The water entering Kristalbad still contains some small amounts of contaminants like heavy metals. In Kristalbad the water is stored alternately for 12 hours in one of the reservoirs. During these 12 hours the heavy metals can be taken up by plants and adsorb to the sediments. Both, uptake and adsorption can be described by a first-order nonequilibrium process. Heavy metals do not degrade. The reservoir can be considered as a well-mixed system. Ignore the time for filling and draining and assume all water resides for 12 hours in the reservoir (volume is constant).

a. Write the mass balance (differential equation) of a heavy metal during the storage of the water in a reservoir. Explain used symbols. (2)

$$V\frac{\partial C}{\partial t} = -k_b m_b\left(S_{b,eq} - S_b\right) - k_s m_s\left(S_{s,eq} - S_s\right)$$
$$= -k_b m_b(K_b C - S_b) - k_s m_s(K_s C - S_s)$$

b. Sketch the change in concentration in the water phase as a function of time during the storage of the water in the reservoir. (2)



c. If the concentration of the heavy metal in the effluent is constant, what will happen to the effectiveness of the post treatment over time and why? (2)

Effectiveness will decrease because uptake and sorption will terminate.

d. In that case, what can be done to increase the effectiveness again? (2)

Dredging and removal of vegetation.

e. What is the purpose/advantage of the alternate filling and draining of the reservoirs? (2)

The cycle of drying and wetting provides oxygen into the soil and increases biological activity that enhances the biological decay of organic matter. More plants can grow that take up contaminants.

f. How many watch towers are there in Kristalbad? (0) 2

Question 19: Water quality standards (6 point)

a. For mercury 38 NOEC (in in μg/l) values are available. The average value of the log(NOEC) values is 0.8 and the standard deviation is 0.89 (Crommentuijn et al. 1997). Calculate the MPA. (2)
MPA protects 95% of the species, so 95% can be affected, i.e. F(x) = 0.05
α = 0.8, $\beta = \frac{\sigma\sqrt{3}}{\pi} = \frac{0.89\sqrt{3}}{\pi}$ = 0.49

$F(x) = \frac{1}{1+\exp((\alpha-x)/\beta)} = 0.05 \rightarrow x = \alpha - \beta ln\left(\frac{1}{F(x)} - 1\right) = 0.8 - 0.49 \cdot$
$ln\left(\frac{1}{0.05} - 1\right) = -0.64$
MPA = $10^{-0.64}$ = 0.23 μg/l

b. Give a reason why you would add an additional safety factor to a derived water quality standard and a reason why not. (2)
Examples in favor of adding an additional safety factor:
- In the field the bioavailability of chemicals is lower than in laboratory tests
- In the field organisms are exposed to a mix of chemicals

Examples in favor of not adding an additional safety factor:
- In laboratory organisms are tested under optimal conditions
- Exposure in the field does not have to be continuous